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Measurement and processing of fetal transcutaneous Pco_2 levels

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1 Introduction

The purpose of each obstetrician is to have all children delivered in an optimal condition. Surveillance of the fetal heart rate should be a guarantee in this regard. Indeed, an optimal cardiotocogram is in 95% of the cases associated with an optimal fetal condition. Although electronic fetal monitoring has contributed to a considerable decrease in perinatal morbidity [25] it must be reminded that asphyxia is not the only factor determining the fetal heart rate. Other influences are e. g. fetal age, behavioral state, congenital anomalies, maternal infections and drug usage [20, 21]. Therefore, a non-optimal cardiotachogram (fetal heart rate pattern) can be a sign of fetal distress, but this is not necessarily always true. In case of a suspicious cardiotachogram further evaluation of the fetal condition is advisable, especially determination of the acid-base equilibrium, which has been shown superior in predicting neonatal condition [13, 26, 27].

However, the method of fetal blood sampling has several disadvantages. The measured acid-base equilibrium is only representative for a very short period of time, since fetal pH may decrease rapidly during labor [8]. Therefore, repeated micro blood sampling is often necessary. Since each sampling often requests a long lasting vaginal examination, the procedure interferes with the normal labor process and is cumbersome to the laboring woman. With regard to the fetus: each sampling is invasive and fetal bleedings and infections have been described, possibly contributing to an increase of fetal morbidity and mortality [11].

Continuous non-invasive surveillance of fetal oxygen supply or its reflection on the acid-base equilibrium, such as fetal transcutaneous Pco_2 ($tcPco_2$) does not have these drawbacks and appears to be a more acceptable and preferable technique, if reliable and adequate assessment of the fetal condition can be obtained.

A major problem with regard to determination of the acid-base equilibrium in intermittently obtained fetal blood samples is the inclusion of air bubbles in the sample. When air bubbles are introduced into the electrode cuvettes of an acid-base analyzer, the measured values cannot be considered reliable. In the Department of Obstetrics and Gynecology of the Vrije Universiteit of Amsterdam, this problem was solved by a "pipe"shaped special collecting vessel and the percentage of successful samplings increased significantly. This special collecting vessel will be discussed.

2 Transcutaneous surveillance of the fetus

Since years it has been possible to measure Po_2 transcutaneously ($tcPo_2$) in the neonatal period. A good correlation was found between $tcPo_2$ and simultaneous Po_2 measurements in arterial blood [7]. In the fetus during delivery however, there are some specific problems that make interpretation of continuous $tcPo_2$ curves more difficult. During the first stage of labor $tcPo_2$ values are close by correlated to Po_2 values in fetal blood samples, but during the second stage of labor this correlation is lost [16]. During the second stage of labor the

fetal head rotates in the pelvis and the $tcPo_2$ electrode can experience pressure by the bony pelvis, resulting in too low measured values [10]. Secondly, the formation of a caput succedaneum decreases capillary circulation of the skin beneath the electrode which results in a falsely reduction of recorded $tcPo_2$ levels [6].

For about 8 years, measurement of tissue pH has been possible. Studies performed during labor show a close correlation to the pH of blood obtained from the fetus according to the microblood sampling technique introduced by SALING, and the pH of umbilical artery blood [9, 23]. However, the current status of continuous pH measurement of the fetus does not permit widespread introduction into clinical practice. The technique is invasive and has risks comparable with fetal blood sampling. Following application of a pH electrode, development of a fetal skin abscess has been described [1]. The distance between the skin surface and the tip of the electrode, as well as the angle under which the electrode is placed (it should be placed perpendicular), are critical to obtain reliable measurements [3]. Even after extensive training the percentage of successful measurements is only 75% [24].

Recently, transcutaneous Pco_2 measurement became available. The transcutaneously measured values of fetal Pco_2 are higher than simultaneously measured values of Pco_2 in fetal arterial blood. There are two reasons for the slightly elevated Pco_2 levels obtained transcutaneously. In the first place, the electrode usually is heated to 39–44 °C. Secondly, the upperlayer of the epidermis has its own CO_2 production [17].

A close correlation has been found between the $tcPco_2$ and the Pco_2 level in fetal capillary blood and in umbilical artery blood [4, 19]. In contrast to continuous monitoring of $tcPo_2$, reliable measurements of $tcPco_2$ appear to be possible during the second stage of labor [16, 19]. The development of a caput succedaneum appears to decrease reliability of $tcPco_2$ levels slightly, but even in its presence a statistically significant correlation to Pco_2 values of fetal scalp blood samples has been described [15]. Continuous transcutaneous Pco_2 monitoring in the fetus might therefore be a valuable method for fetal surveillance. Presently available literature indicates that every acute deterioration of the fetal condition during labor was preceded by a raise of fetal $tcPco_2$ [15].

3 Fetal $tcPco_2$ research and computerization

The working group "New methods" of the European Community project "Perinatal Monitoring" is evaluating fetal $tcPco_2$ monitoring in a multicenter study. The Department of Obstetrics and Gynecology of the Vrije Universiteit of Amsterdam is one of the co-operating centers. Following the introduction of this multicenter study, we developed a plan to record automatically a multitude of variables such as fetal heart rate, fetal $tcPco_2$ and maternal uterine activity.

As our department has a special interest in factors influencing fetal heart rate patterns, we will compare the predictive value of the fetal $tcPco_2$ measurements with that of the cardiotachogram. For this purpose a quantitative analysis of both variables of the fetal condition is desirable.

Besides, we record maternal $tcPco_2$ levels to study the influence of the maternal levels on the fetal $tcPco_2$. During pregnancy there is an increase in maternal alveolar ventilation of 60 to 70% accompanied by an increased maternal Po_2 and a decreased Pco_2 [2, 5]. During labor this hyperventilation is more pronounced and because of a reduced maternal expiratory reserve volume, marked changes in partial pressures may occur [5]. Hyperventilation also causes vasoconstriction resulting in reduced blood supply to different organs. Experimental research in sheep showed a reduction of uterine blood flow after hyperventilation [12]. Research in human showed an increased incidence of metabolic acidosis of both mother and fetus following maternal hyperventilation [14].

To reach our aim we need to record: fetal heart rate, maternal uterine activity, fetal $tcPco_2$, heat production of the fetal $tcPco_2$ electrode, maternal $tcPco_2$, heat production of the maternal $tcPco_2$ electrode, and events during labor (e. g. rupture of the membranes, vaginal examination, fetal blood sampling etc.).

Under usual circumstances the cardiotocogram is recorded with a Hewlet Packard 8030 on paper at a speed of 1 or 3 cm/minute. The fetal and maternal $tcPco_2$ are recorded on paper at a speed of 1 cm/2 minutes (Radiometer equipment). Deviation of the heat production of both electrodes can be collected by digital read out. Events are written down in a note book. Such a situation makes evaluation of data very complex. Computerization of these data therefore is desirable and has the following advantages:

- Synchronization of signals
  Many variables can be recorded synchronously which solves the problem of speed differences between the various recording machines.
- No limitation of the number of signals that can be recorded
  From the Radiometer equipment the two $tcPco_2$ signals of mother and fetus and the two accompanying heat deviation curves can be recorded continuously.
- Data reduction
  The current situation creates a disorderly stock of different files with a lot of different papers, making evaluation a tough job. Stocking them in a computer gives a clean desk.
- Orderly and variable display
  It makes presentation of the material easier and more flexible and provides more insight into it.
- Quantitative analysis

We already have some experience with computerization of data. The technique was at first used in fetal behavioral studies, done from 1981 onwards in our department [22]. Figure 1 is an example of a recording of fetal heart rate and a variety of fetal movements in relation to fetal behavioral states.

Since the earlier described study on fetal and maternal $tcPco_2$ levels is performed during labor, it is not possible to transmit all data directly into the computer which we use for further processing and evaluation. For this reason we apply a digital VT 103 terminal with built-in LSI-11/02 processor multifunction board MXV 11, 16 KV RAM, 8-channel AD-converter, parallel unit DRV 11 and dual TU 58 tape drive for DECTAPE-II cartridges; an interface, developed by our technical service center, is used to adapt the fetal heart rate signal of the Hewlet Packard 8030 A to the DRV 11 parallel unit. It is a small, easily transportable unit that can be placed in every labor

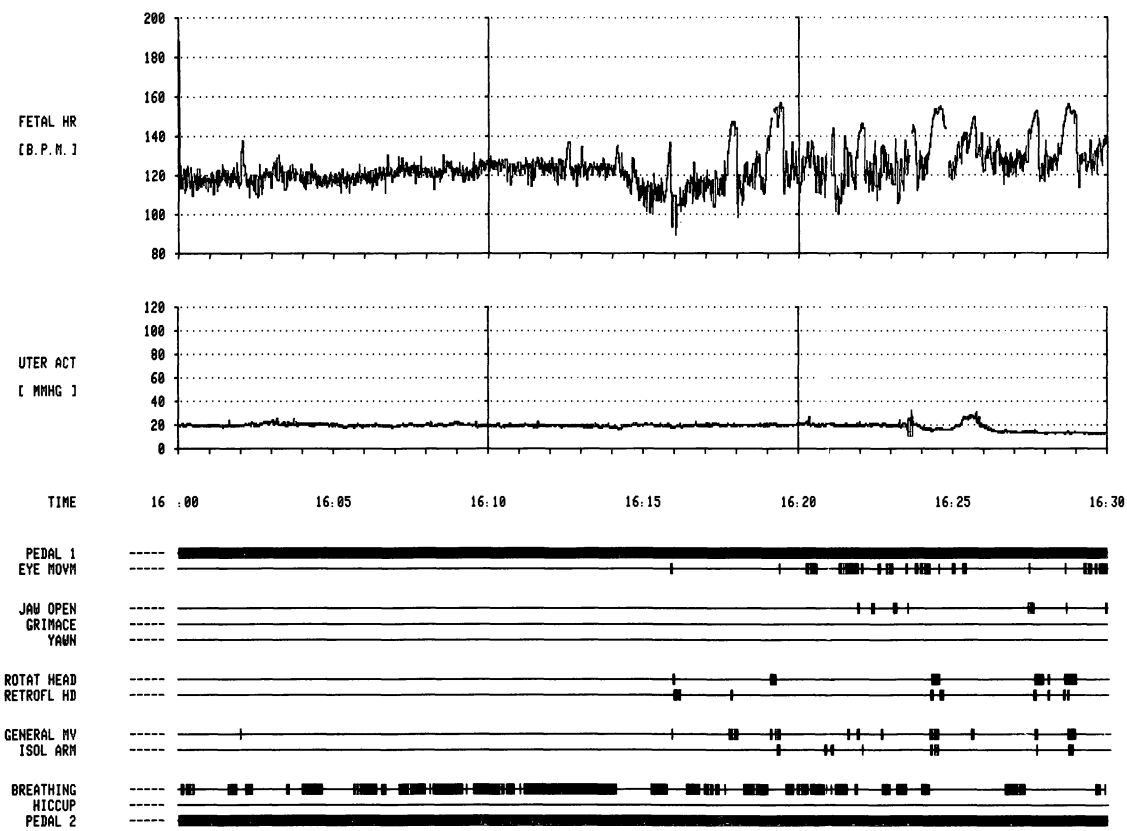

Figure 1. Fetal heart rate and a variety of fetal movements in relation to fetal behavioral states.

room. All signals are transmitted synchronously to the datalogger. Events are marked by a pedal. A continuous registration of four hours is easily obtainable. Afterwards, the information filed on the tape cartridge is copied to the PDP-11/34 computer for proper evaluation, including quantitative analysis. The software for the datalogger, also developed by our technical service center, is written in fortran IV.

4 Method for de-bubbling fetal scalp blood samples

Blood samples, taken from the fetal scalp and collected into long glass capillaries, often contain air bubbles.

When one introduces the content of such capillaries directly into a pH-bloodgas-analyzer, one causes a disturbance of the measurement because blood as well as air bubbles will enter into the measuring chambers and the connecting capillaries. These air bubbles lead to false values for the Po_2 and the Pco_2 of the sample because of their different O_2 and CO_2 content and the air bubbles influence the pH when they affect the conductivity between the pH electrode and the reference cell.

To prevent these drawbacks we drain, after collection in a regular glass capillary, the fetal scalp blood samples into a special "pipe"shaped collecting vessel (figure 2), by which procedure the air bubbles escape from the blood sample. The "pipe" is subsequently connected to the suction device of the analyzer.

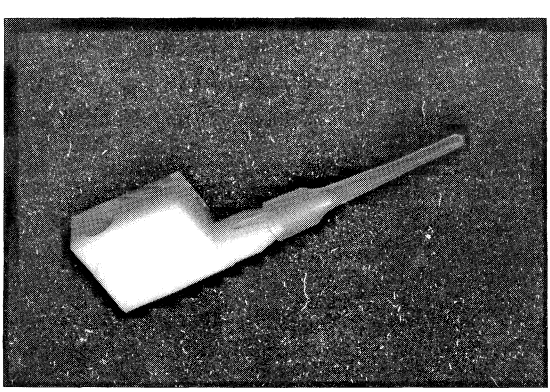

Figure 2. Pipe-shaped special collecting vessel.

SILVERMAN already showed that admixture with air as such, does not influence the values for pH and the blood gasses in fetal blood samples [18].

In our laboratory it was investigated whether the debubbling procedure described above affects the values for pH and blood gasses. A venous blood sample from an adult volunteer was introduced into a glass syringe of 10 ml. This syringe already contained some glass beads and a heparin solution. The plunger was in the most downward position before the blood was introduced. The air was removed. Next the content of the syringe was mixed thoroughly by gentle turning the syringe upside down many times. Then 12 hockey stick shaped glass capillaries of about 40 cm of length and having a content of about 0.15 ml, were filled anaerobically from the syringe. Four of these capillaries were drained into the "pipe"shaped special collecting vessels, just prior to the measurement of the sample (one sample was lost). The next four samples were directly introduced from the glass capillary into the analyzer. The last four samples again were introduced into the collecting vessels prior to their measurement. The whole procedure took 43 minutes.

The results are summarized in table I. The values of the table show that the procedure of transfer-

Table I. The effect of transferring blood from glass capillaries (CAP) into special collecting vessels (SCV) on the values for pH and the blood gasses (KPa). The instrument used was a Corning 178 pH/Blood Gas Analyser.

	no	pH	Pco_2	Po_2
SCV	1	7.398	5.69	4.12
	2	7.392	5.82	4.16
	3	7.400	5.72	4.20
mean		7.397	5.76	4.16
CAP	4	7.397	5.85	4.15
	5	7.394	5.73	4.07
	6	7.397	5.82	4.10
	7	7.389	5.97	4.25
mean		7.396	5.82	4.16
SCV	8	7.389	5.88	4.20
	9	7.388	5.91	4.21
	10	7.394	5.87	4.24
	11	7.389	5.97	4.25
mean		7.390	5.91	4.23

ring blood samples from the glass capillaries into the "pipe"shaped special collecting vessels, has no effect on the values for pH and the blood gasses.

We concluded that blood samples, collected in a glass capillary and contaminated with air bubbles, may validly be analyzed after having been debubbled by the method described above.

5 Conclusions

Evaluation of fetal acid-base equilibrium has proven to be beneficial in fetal surveillance, especially in cases of suspicious fetal heart rate patterns.

The currently used fetal blood sampling technique developed by SALING has an invasive character for both mother and fetus. Furthermore, it reflects only one measuring point in a continuously changing situation. Continuous $tcPco_2$ monitoring does not have these disadvantages. Therefore, when the measurements are proven to be reliable, it will be a valuable addition to our diagnostic possibilities regarding prediction of fetal distress.

Automatic recording and processing, and quantitative analysis of fetal $tcPco_2$ curves in relation to other parameters of fetal and maternal condition will provide more insight into the risks of the labor process for the fetus.

Summary

Because asphyxia is not the only factor influencing fetal heart rhythm, a non-optimal cardiotachogram is not necessarily a sign of fetal distress. It makes further evaluation of the fetal condition advisable, especially determination of the acid-base equilibrium.

The method of fetal blood sampling, introduced by SALING, has a number of disadvantages for mother and fetus, because of the invasiveness for both. Further, the measured acid-base equilibrium is only representative for a very short period of time and often repeated microblood sampling is necessary.

A major problem with regard to determination of the acid-base equilibrium in intermittently obtained fetal blood samples is the inclusion of air bubbles in the sample. When they are introduced into the electrode cuvettes, the measured values cannot be considered reliable. The problem was solved in the Department of Obstetrics and Gynecology of the Vrije Universiteit of Amsterdam with a "pipe"shaped special collecting vessel. Similar measuring results were obtained with the formerly used glass capillary method and the special collecting vessel method.

Continuous, non-invasive methods have been pursued to avoid the above mentioned problems. Fetal transcutaneous Po_2 measurement has been possible for years, but does not provide adequate information during the important second stage of labor because of methodological problems.

Continuous fetal tissue pH surveillance is possible, but it also has an invasive character and is technically difficult to perform, leading to many methodological failures.

Recently, continuous transcutaneous Pco_2 measurement $tcPco_2$ became available. A good correlation was found with simultaneously measured Pco_2 levels in fetal blood samples and with those of umbilical artery blood.

Presently, available literature indicates that acute deterioration of the fetal condition during labor was always preceded by a raise of fetal $tcPco_2$. Therefore, fetal $tcPco_2$ surveillance potentially is a valuable adjunct to monitor the fetal condition, if reliable and adequate assessment can be obtained. The method will be evaluated in a multicenter study of the working group "New Methods" of the European Community project "Perinatal Monitoring".

In our department we are comparing the predictive value of fetal $tcPco_2$ measurement with that of the cardiotachogram. Besides, we are studying the influence of maternal $tcPco_2$ on fetal $tcPco_2$ levels. To reach our aim we need to record: fetal heart rate, maternal uterine activity, fetal $tcPco_2$, heat consumption of the fetal $tcPco_2$ electrode, maternal $tcPco_2$, heat consumption of the maternal $tcPco_2$ electrode and events during labor. Computerization of these data is desirable and has following advantages:

- synchronisation of signals,
- no limitation of the number of signals that can be recorded,
- data reduction,
- orderly and variable display,
- quantitative analysis.

Our technical service center developed a system in which the data are collected by a digital VT 103 datalogger and then transmitted to a P. D. P. 11/34 computer for further processing and evaluation.

Keywords: Capillary blood analysis, fetal monitoring, measurement error, transcutaneous blood gas monitoring.

Zusammenfassung

Messung und Auswertung der fetalen transkutanen Pco_2-Werte

Weil eine Asphyxie nicht der einzige Faktor ist, der das fetale Herzfrequenzmuster beeinflußt, ist ein nicht optimales Kardiotokogramm nicht unbedingt ein Zeichen eines „fetal distress". Es ist deshalb wünschenswert, eine weitere Untersuchung des fetalen Zustandes zu berücksichtigen, insbesondere durch die Bestimmung des Säure-Basen-Haushaltes.

Die Methode der Fetalblutanalyse, die SALING entwikkelte, zeigt eine Reihe von Nachteilen für Mutter und Kind, weil sie für beide invasiv ist. Der gemessene Säure-Basen-Haushalt ist weiterhin nur für sehr geringe Zeit aussagekräftig und eine Wiederholung der Fetalblutanalyse ist oft notwendig.

Ein großes Problem angesichts der Bestimmung des Säure-Basen-Haushaltes besteht darin, daß in den intermittierend gewonnenen fetalen Blutproben Luftblasen auftauchen können. Wenn sie in die Elektrodenküvetten eindringen, können die gemessenen Werte nicht zuverlässig bewertet werden. Dieses Problem wurde in der Abteilung für Geburtshilfe und Gynäkologie der Freien Universität in Amsterdam durch die Einführung eines besonderen Sammelgefäßes gelöst. Ähnliche Meßergebnisse wurden mit der früher benutzten Glaskapillarmethode und der besonderen Sammelgefäßmethode erreicht.

Kontinuierliche, nicht-invasive Methoden sind untersucht worden, um diese obengenannten Probleme zu vermeiden. Transkutane Po_2-Messungen sind seit Jahren möglich gewesen, aber sie liefern aufgrund methodischer Probleme keine ausreichende Information während der wichtigen zweiten Phase der Geburt.

Eine kontinuierliche fetale Gewebe-pH-Überwachung ist möglich, aber auch sie hat einen invasiven Charakter und bereitet technische Schwierigkeiten, die zu vielen methodischen Mißerfolgen führen.

Neuerdings ist die kontinuierliche transkutane Pco_2-Messung möglich geworden. Es wurde eine gute Korrelation mit den simultan gemessenen Pco_2-Werten in fetalen Blutproben und mit denen des Nabelarterienblutes gefunden.

Zur Zeit zeigt die vorhandene Literatur, daß einer akuten Verschlechterung des fetalen Zustandes während der Geburt immer ein Anstieg der fetalen $tcPco_2$ vorausging. Daher ist die fetale $tcPco_2$-Überwachung potentiell ein wertvoller Zusatz, um den fetalen Zustand zu überwachen, wenn zuverlässige und hinreichende Registrierungen erhalten werden können. Diese Methode wird in einer Multizenter-Studie der Arbeitsgruppe „New Methods" des EC Projektes „Perinatal Monitoring" ausgewertet.

In unserer Abteilung vergleichen wir den vorhergesagten Wert der fetalen $tcPco_2$-Messung mit dem des Kardiotokogramms. Außerdem studieren wir den Einfluß maternaler $tcPco_2$- auf fetale $tcPco_2$-Werte. Dazu sind folgende Registrierungen erforderlich: fetale Herzfrequenz, mütterliche uterine Aktivität, fetaler $tcPco_2$, Heizleistung der fetalen $tcPco_2$ Elektrode, mütterlicher $tcPco_2$, Heizleistung der mütterlichen $tcPco_2$ Elektrode und Ereignisse während der Geburt. Die Datenspeicherung im Computer bietet folgende Vorteile:

- Synchronisierung der Signale,
- Keine Einschränkung der Zahl der Signale, die registriert werden können,
- Reduktion der Daten,
- Option verschiedener Darstellungsformen der Ergebnisse,
- Quantitative Analyse.

Unser Institut hat ein System entwickelt, das die Daten durch einen digitalen V 1103 Datenspeicher erfaßt; diese werden anschließend auf einen P. D. P. 11/34 Computer zur weiteren Verarbeitung und Auswertung übermittelt.

Schlüsselwörter: Fetale Überwachung, kapillare Blutanalyse, Meßfehler, transkutane Blutgasmessung.

Résumé

Acquisition et traitement de la mesure de la Pco_2 transcutanée fœtale

Comme l'asphyxie n'est pas le seul facteur influençant le rythme cardiaque fœtal, un tracé de fréquence cardiaque imparfait n'est pas obligatoirement un signe de souffrance fœtale. En présence de dernier il est souhaitable d'effectuer une évaluation complémentaire de l'état de l'enfant et en particulier une détermination de l'équilibre acido-basique.

La méthode de prélèvement de sang fœtal mise au point par SALING présente l'inconvénient d'être invasive à la fois pour la mère et pour le fœtus. De plus, l'évaluation de l'équilibre acide-base qu'elle fournit n'est représentative que d'une très courte période et des microprélèvements répétés sont souvent nécessaires.

La présence de bulles d'air dans les prélèvements constitue un problème majeur pour la détermination de l'équilibre acido-basique à partir des prélèvements discontinus. Quand elles sont présentes à l'intérieur de l'électrode, la mesure ne peut pas être considérée comme fiable. Ce problème a été résolu, dans le département de Gynécologie-Obstétrique de l'Université de Vrije à Amsterdam, au moyen d'un tube collecteur de forme spéciale. Des mesures identiques ont été obtenues avec les anciens tubes capillaires en verre et avec le collecteur spécial.

Pour éviter les problèmes mentionnés ci-dessus, on a recherché des méthodes non invasives de mesure continue. La mesure de la Po_2 transcutanée fœtale est possible depuis plusieurs années, mais du fait de problèmes mét-

hodologiques, ne fournit pas d'information pertinente pendant la seconde partie du travail pourtant importante. La surveillance continue du pH tissulaire fœtal est possible mais elle a également un caractère invasif et du fait de sa difficulté technique entraîne beaucoup d'échecs méthodologiques.

Récemment, des méthodes de mesure continue de la Pco_2 sont devenues disponibles. Une bonne corrélation a été trouvée avec la Pco_2 mesurée sur des prélèvements simultanés effectués simultanément sur le scalp du fœtus ou sur l'artère ombilicale.

Actuellement, la littérature disponible indique qu'une détérioration aiguë de l'état de l'enfant au cours du travail est toujours précédée par une élévation de la $tcPco_2$ fœtale. La surveillance de la $tcPco_2$ fœtale représente donc un complément potentiel précieux pour le monitorage de l'état fœtal, sous réserve d'en permettre une évaluation fiable et pertinente. La méthode sera évaluée dans une étude multicentrique du groupe de travail «Méthodes nouvelles» du projet «Monitorage Perinatal» de la Communauté Européenne.

Dans notre département, nous comparons la valeur prédictive de la mesure de la $tcPco_2$ fœtale et celle des tracés de fréquence cardiaque fœtale. En outre, nous étudions l'influence de la $tcPco_2$ maternelle sur les valeurs de $tcPco_2$ fœtale. Pour cela, nous devons enregistrer: la fréquence cardiaque fœtale, l'activité utérine, les $tcPco_2$ du fœtus et de la mère, les consommations de chaleur des deux électrodes à $tcPco_2$ fœtale et maternelle et les évènements survenant pendant le travail. Un traitement informatisé de ces données est souhaitable et présente les advantages suivants:

- synchronisation des signaux,
- pas de limitation du nombre de signaux que l'on peut enregistrer,
- réduction des données,
- affichage ordonné et variable,
- analyse quantitative.

Notre centre de service technique a développé un système dans lequel les données sont recueillies au moyen d'un enregistreur digital VT 103 puis transmises à un ordinateur PDP 11/34 pour traitement ultérieur et évaluation.

Mots-clés: Analyse du sang capillaire, erreur de mesure, mesure de la Pco_2 transcutanée, monitorage fetal.

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